ARMY RESEARCH LABORATORY

Distribution of Fragments Resulting From Polygonal Object Fracture

by Andrew M. Neiderer and Charles E. Hansen

ARL-TN-182 September 2001

Approved for public release; distribution is unlimited.

Army Research Laboratory
Aberdeen Proving Ground, MD 21005-5067

ARL-TN-182 **September 2001**

Distribution of Fragments Resulting From Polygonal Object Fracture

Andrew M. Neiderer and Charles E. Hansen
Computational and Information Sciences Directorate, ARL

Abstract

This report presents an approach for the distribution of fragments resulting from the fracture of a polygonal object. Earlier research discussed a technique for polygonal object fracture. These "interior" clipped polygons represent the debris resulting from a munition perforating an urban structure in the U.S. Army Research Laboratory (ARL) Dismounted Infantry Simulator (DISim). This is just one component of DISim, which is a tool that provides for the training of military operations in urban terrain (MOUT). It is important to include any data that better prepares the soldier for this often chaotic environment.

Contents

INTENTIONALLY LEFT BLANK.

List of Figures

INTENTIONALLY LEFT BLANK.

1. Introduction

As the number of urban centers continues to increase worldwide, the likelihood that U.S. forces will be called upon to conduct military operations in urbanized terrain (MOUT) increases as well. Whether troops are addressing internal disorder here within the U.S. or restoring political stability in a foreign land, the objectives in a MOUT mission remain the same: seize, clear, and then defend the area.

Urban fighting often reduces to an infantry fight. A first objective should be securing places of cover or concealment (e.g., a strategically located building). This often involves moment-to-moment decision making by the individual soldier; only reacting under hostile conditions results in a higher probability of injury or casuality. Therefore, planning and preparation are critical to minimize loss and ensure success within this environment.

The U.S. Army Research Laboratory (ARL) Dismounted Infantry Simulator (DISim) is a tool designed for training U.S. forces in simulated urban environments. For rehearsal in potentially chaotic situations, many components have already been integrated, including (1) dynamic terrain which effects mobility, (2) shadows cast by objects and/or (3) battlefield smoke and dust which restrict visibility, (4) noise from blasts that can be deafening, and (5) munitions perforating urban structures.

A previous technical report* addressed fracturing of polygonal objects in DISim. The algorithm was necessary for simulating an assault on a building, which is a common combat task in built-up areas. Breaching operations improve mobility by providing access to building interiors. This is necessary because predictable entries, such as accessible windows and doors, are more likely to be booby trapped. Creating an entry point could be accomplished by affixing an entry munition to a wall, or it could involve continued and concentrated gun fire to generate a man-sized hole. The resultant rubble should also be a concern, since secondary effects from strewn debris may also result in soldiers taken out of action during combat. Rubble in DISim consists of the "interior" polygons resulting from a Sutherland-Hodgman (SH) polygon clip at the point of impact.

The following sections present a technique for distributing these polygons in a simulation environment. A piece of debris is placed in one of two triangular fields (TF): exterior, the reflection field (RlF), or interior, the refraction field (RrF), at the point of impact. The intent is to provide additional data to the soldier on foot, which may assist in mission success.

Note that the targets in our simulation database (the McKenna site in Fort Benning, GA) are two-dimensional. Therefore it was necessary to extrude planar polygons by some reasonable amount before displaying.

*Neiderer, A. M., M. A. Thomas, and R. Pearson. "A Fracturing of Polygonal Objects." ARL-TR-1649, U.S. Army Research Laboratory, Aberdeen Proving Ground, MD, April 1998.

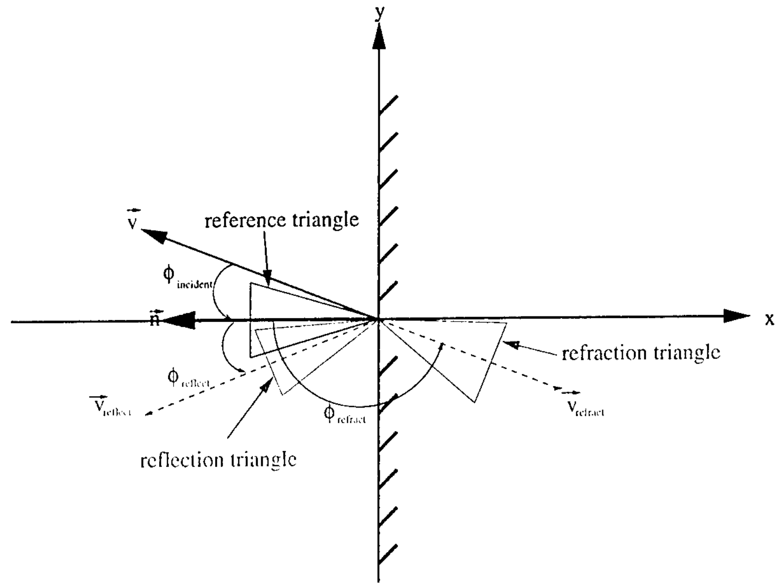

Figure 1: Triangular reflection and refraction rubble fields.

2. Triangular Rubble Fields

By neglecting material properties of the projectile p and the target t, perforation and resultant debris distribution reduce to geometric considerations. Figure 1 illustrates an example of a projectile with velocity vector $\vec{v}$ striking a target at the origin in the $x = 0$ plane. The outward facing normal vector $\vec{n}$ at the point of impact coincides with the negative x-axis.*

In this initial release we chose a triangular shape for representing fields both interior and exterior at the point of breach. A reference triangle (RT) is constructed with its apex at the origin, which is the point of interaction of p and t. Note that $\vec{n}$, or its unit normal $\hat{u} = \vec{n}/|\vec{n}|$, is the bisector at this point (see Figure 1).

Material properties are not totally disregarded. The size of each field is empirically determined from data available at the time of simulation. Affine transformations of the RT result in reflection and refraction triangles. This geometric primitive also simplifies the placement of rubble, which is discussed in section 3.

*Geometric manipulation of the target, namely a translation followed by two successive rotations, resulted in this situation. The idea is to align $\vec{n}$ at the point of interaction with a principal axis, thus simplifying computation of the rubble fields. The original conditions for an arbitrary orientation are restored by performing inverse geometric transformations. See Neiderer[1] for a more thorough discussion.

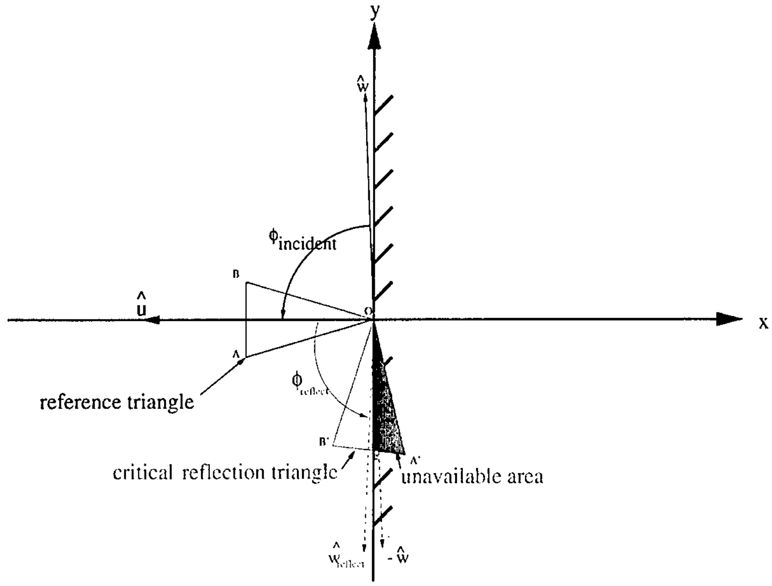

Figure 2: Critical reflection triangle. Shaded triangle is a nonactive area.

2.1. Reflection Triangle

The velocity vector $\vec{v}$, which is normalized to $\hat{w} = \vec{v}/|\vec{v}|$, makes an angle $\phi_{incident}$ with the closest primary axis in counterclockwise order. In Figure 2 this is the negative x-axis. The law of reflection states that $\phi_{incident} = \phi_{reflect}$. A reference triangle AOB with apex at the origin O is constructed about the negative x-axis and rotated counterclockwise by $\phi_{incident}$ degrees; the result is the reflection triangle (RlT). Such a rotation in this example results in the reduced reflection triangle $B'eO$ for debris distribution because an active RlT must lie in the same half space as the projectile. Here the reflection half space is defined by negative x values, and the refraction half space corresponds to positive x. The final triangle of smaller size is called the critical reflection triangle (CRlT). Similiarly, the active area of the refraction triangle must lie completely within the refraction half space. This is discussed in the next section.

2.2. Refraction Triangle

A refraction triangle (RrT) is constructed about $-\hat{w}$, a unit vector in the opposite direction of the velocity direction vector. The refraction angle $\phi_{refract}$ is defined to be $\pi - \phi_{reflect}$ (recall that $\phi_{reflect}$ is the angle that $\hat{w}$ makes with a primary axis for a counterclockwise rotation). The rotation of the RT can also result in a reduced triangle for debris distribution, called the critical refraction triangle (CRrT) (see Figure 3). Debris distributed in this triangle increases as $\hat{w} \to \hat{u}$.

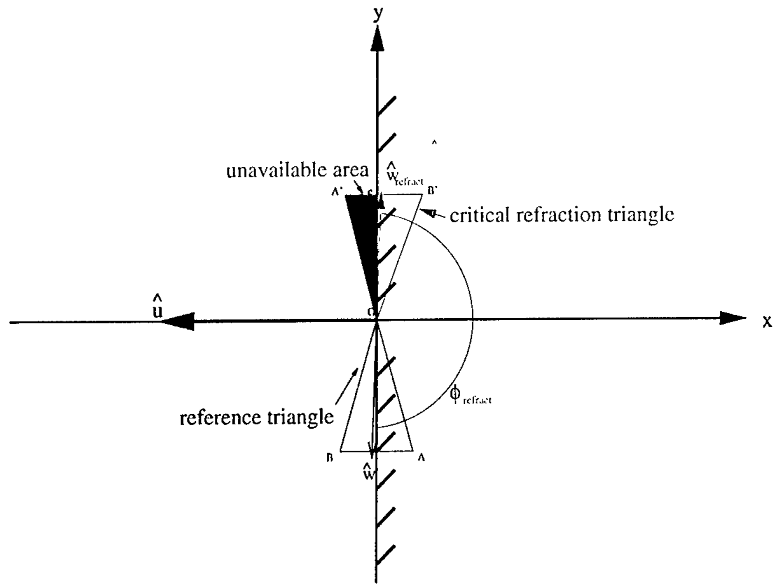

Figure 3: Critical refraction triangle. Shaded triangle is a nonactive area.

3. Rubble Distribution

A simple linear relationship, based on the angle between $\hat{u}$ and $\hat{w}$, is used for determining which field to assign an interior polygon. As $\hat{w} \rightarrow \hat{u}$, it is more likely that a piece of rubble is propelled in the same direction. The existing empirical relationship assigns a 90% chance that a polygon fragment is assigned to RrT when $\hat{w}$ and $\hat{u}$ are coincident. The opposite is true as $\hat{w}$ approaches the grazing angle, i.e., $\hat{w}$ nearly perpendicular to $\hat{u}$. The result is a reflected polygon fragment (recall that ricochet is ignored for now). Angles somewhere in between result in a more even distribution of debris.

Once it has been determined which TF to populate, two pseudo-random Gaussian values U and V from the distribution function $N[0.5, 0.02083]$, where mean $\mu = 0.5$ and variance $\sigma^2 = 1/48 \approx 0.02083$, are generated for a piece of debris. As illustrated in Figure 4, a point e with coordinates (x_e, y_e) on the line segment $\overline{AB}$ is computed using the linear relationship

$$(x_A, y_A) + U(x_B - x_A, y_B - y_A).$$

Then, using our V value, a point f on $\overline{eO}$ is computed in a similiar fashion. This point is the location for the piece of rubble. The procedure used in picking U and V ensures that each point f will in fact be within the TF.

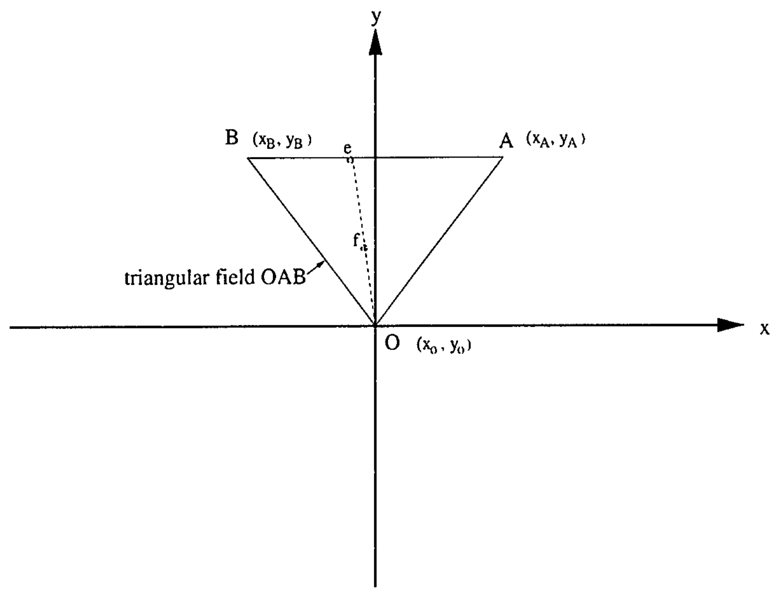

Figure 4: Rubble placement.

4. Results and Future Work

Another component has been added to ARL's DISim for a more realistic simulation of an urban environment under siege: rubble generation and distribution resulting from the assault of urban structures. It is important to include events in simulation that may have an impact on the soldier's decision making. Strewn debris in a hostile environment must be dealt with both efficiently and effectively.

Further research should include computations with a more comprehensive database of actual material types, both projectile and target. An example is a thick reinforced concrete structure. Also, not every collision results in penetration, even at zero obliquity. Most shots impact a target at an angle of obliquity, further reducing penetration. In the case of repeated gun fire, it is difficult to hold the weapon steady and repeatedly hit the same point on a wall; dust created by the bullet strikes makes precise aiming difficult. Therefore, we need to address ricochet and its display, and at the other extreme structural failure or total collapse. We will address these issues in future releases.

INTENTIONALLY LEFT BLANK.

NO. OF COPIES	ORGANIZATION
2	DEFENSE TECHNICAL INFORMATION CENTER DTIC OCA 8725 JOHN J KINGMAN RD STE 0944 FT BELVOIR VA 22060-6218
1	HQDA DAMO FDT 400 ARMY PENTAGON WASHINGTON DC 20310-0460
1	OSD OUSD(A&T)/ODDR&E(R) DR R J TREW 3800 DEFENSE PENTAGON WASHINGTON DC 20301-3800
1	COMMANDING GENERAL US ARMY MATERIEL CMD AMCRDA TF 5001 EISENHOWER AVE ALEXANDRIA VA 22333-0001
1	INST FOR ADVNCD TCHNLGY THE UNIV OF TEXAS AT AUSTIN 3925 W BRAKER LN STE 400 AUSTIN TX 78759-5316
1	US MILITARY ACADEMY MATH SCI CTR EXCELLENCE MADN MATH THAYER HALL WEST POINT NY 10996-1786
1	DIRECTOR US ARMY RESEARCH LAB AMSRL D DR D SMITH 2800 POWDER MILL RD ADELPHI MD 20783-1197
1	DIRECTOR US ARMY RESEARCH LAB AMSRL CI AI R 2800 POWDER MILL RD ADELPHI MD 20783-1197

NO. OF COPIES	ORGANIZATION
3	DIRECTOR US ARMY RESEARCH LAB AMSRL CI LL 2800 POWDER MILL RD ADELPHI MD 20783-1197
3	DIRECTOR US ARMY RESEARCH LAB AMSRL CI IS T 2800 POWDER MILL RD ADELPHI MD 20783-1197

ABERDEEN PROVING GROUND

NO. OF COPIES	ORGANIZATION
2	DIR USARL AMSRL CI LP (BLDG 305)

NO. OF COPIES	ORGANIZATION
	ABERDEEN PROVING GROUND
8	DIR USARL AMSRL CI AS R C KASTE P JONES M THOMAS C HANSEN AMSRL CI CT A NEIDERER (4 CPS)

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	September 2001	Final, October 2000–April 2001

4. TITLE AND SUBTITLE
Distribution of Fragments Resulting From Polygonal Object Fracture

5. FUNDING NUMBERS
1TEDNC

6. AUTHOR(S)
Andrew M. Neiderer and Charles E. Hansen

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Research Laboratory
ATTN: AMSRL-CI-CT
Aberdeen Proving Ground, MD 21005-5067

8. PERFORMING ORGANIZATION REPORT NUMBER
ARL-TN-182

9. SPONSORING/MONITORING AGENCY NAMES(S) AND ADDRESS(ES)

10.SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This report presents an approach for the distribution of fragments resulting from the fracture of a polygonal object. Earlier research discussed a technique for polygonal object fracture. These "interior" clipped polygons represent the debris resulting from a munition perforating an urban structure in the U.S. Army Research Laboratory (ARL) Dismounted Infantry Simulator (DISim). This is just one component of DISim, which is a tool that provides for the training of military operations in urban terrain (MOUT). It is important to include any data that better prepares the soldier for this often chaotic environment.

14. SUBJECT TERMS
fracture, polygon clip

15. NUMBER OF PAGES
12

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18 298-102

INTENTIONALLY LEFT BLANK.